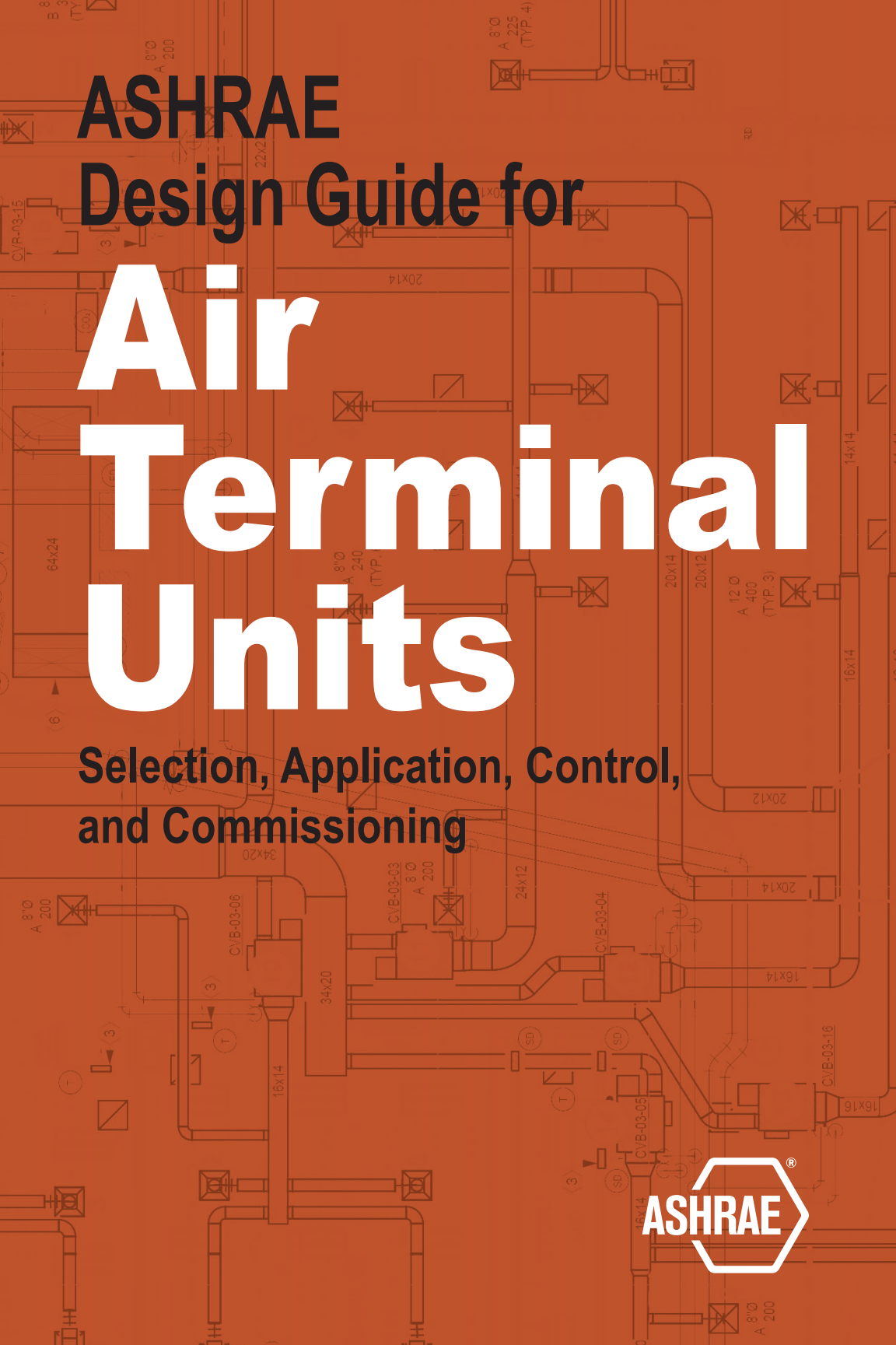
ASHRAE Design Guide for

Air Terminal Units

Selection, Application, Control, and Commissioning



ASHRAE Design Guide for Air Terminal Units

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ASHRAE Design Guide for Air Terminal Units

Selection, Application, Control, and Commissioning

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As a member of AHRI, Faris served as chair of the Air Control and Distribution Devices Section and on the subcommittees for Standards 880 and 885. He also served as chair of the Heat Transfer Products Section and Room Fan Coils Subcommittee and chaired AHRI Research Project 8012. He currently serves AHRI on the Systems Steering Committee and the Certification Programs and Policy Committee and is a corresponding member of the Government Affairs Committee. Faris also chaired the Variable Air Volume Research Consortium at Texas A&M Engineering Experiment Station and is a recipient of the AHRI Richard C. Schultz Award.

Jerry M. Sipes

Before his passing in 2016, Jerry M. Sipes, PhD, PE, was vice president of engineering for Price Industries and a registered professional engineer in two states, with more than 20 years of experience in the HVAC field. His technical areas of interest included heat transfer, fluid flow, human thermal comfort, HVAC, and acoustics. He received his PhD in mechanical engineering from Kansas State University (KSU) in 1998. In the field of engineering research and education, Sipes served for 10 years as a senior researcher at KSU's Institute for Environmental Research and lectured part time for the Mechanical Engineering Department.

Sipes was a member of ASHRAE TC 5.3 for more than a decade, a TC 5.3 Handbook reviser from 2001 to 2011, and the chair of TC 5.3 from 2014 to 2016. He was also a longtime member of TC 2.1 and was its chair from 2003 to 2005. He served as chair of SPC 200 and participated on numerous other SPCs, including SPC 130 and SPC 55. Sipes was an ASHRAE Distinguished Lecturer in 2012 and 2013 and received several ASHRAE awards: the Ralph G. Nevins Physiology and Human Environment Award (2001), the Distinguished Service Award (2014), and the Standards Achievement Award (2016). He also participated in ASHRAE RP-864 and RP-822.

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Ronald G. Holdaway, PE, LEED AP, holds a Bachelor of Science in Mechanical Engineering degree from Tennessee Technological University (TTU) in 1974. From 1974 to 2014, he served various roles at a major consulting engineering firm in Nashville, Tennessee, including design engineer, project manager, mechanical department head, principal, chief mechanical engineer, and chief of technical resources. He has designed more than 200 hospital projects and numerous other high-tech projects, including sporting venues, arena and stadium projects, television studios, data centers, large central energy plants, and ground-source geothermal projects. In 2014, Holdaway started RG Holdaway Consulting, LLC, to continue serving hospital and energy-focused projects and clients. He holds an active and/or inactive status as a licensed professional engineer in 26 states.

An ASHRAE member since 1974, Holdaway joined as a student member while at TTU. He was an active participant in the Nashville Chapter for 40 years and is now a member of the Northwest Florida Chapter. He is a voting member of SPC 113 and a corresponding member of SPC 170.

He has also served as president of the Nashville Chapter of ASME and is a current member of National Fire Protection Association (NFPA), American Society for Healthcare Engineering (ASHE), and Construction Specifications Institute (CSI). Holdaway is the author of the ASHE publication *Mechanical Systems Handbook for Health Care Facilities* (2015) and throughout his career has developed design guidelines for major health care companies. He is also the author of numerous magazine articles.

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Gaylon Richardson is president of Engineered Air Balance, a testing, balancing, and HVAC commissioning firm with offices in Dallas, Houston, and San Antonio, Texas. He is also a Certified Test and Balance Engineer

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Megan M. Tosh, PE, BEMP, is a product manager at Integrated Environmental Solutions Limited and an adjunct instructor at the University of Portland in Oregon. She earned her Bachelor and Master of Science in Mechanical Engineering degree from the University of Central Florida in Orlando and began volunteering with ASHRAE immediately thereafter. As a member of ASHRAE, Tosh has presented at numerous ASHRAE conferences on topics including career development and energy modeling techniques. She earned the Distinguished Service Award in part due to her roles as chapter president of the Central Florida Chapter, Young Engineers in ASHRAE (YEA) regional coordinator for Region XII, regional vice chair of student activities for Region IV, chair of the YEA Committee, and vice chair of the Electronic Communications Committee.

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This design guide is accompanied by supplemental materials that can assist in the selection, application, control, and commissioning of air terminal units and that can be found at www.ashrae.org/ADGATU.

Preface

Air terminal units play an important role in the energy consumption of a building and ultimately the comfort of occupants, both acoustic and thermal. This design guide was created with the goal of producing a best practice guide to aid in the selection of air terminal units by design engineers. The team that produced this guide comprised a consulting engineer, manufacturers of air terminal units, a balancing commissioning and testing engineer, and a manufacturer's representative.

This guide was written in regards to current North American codes, standards, and design practices. It is intended to aid design engineers in selecting types of air terminal units and to explain methods for sizing units while maximizing occupant comfort and energy efficiency. It also details how to meet sound requirements and how to estimate life-cycle costs. The authors' intent was to cover the existing product base as well as new application and component improvements.

ASHRAE Technical Committee (TC) 5.3, Room Air Distribution, is the cognizant committee that reviewed and ultimately voted to approve this guide. TC 5.3 is concerned with the distribution, diffusion, and conditioning of air within rooms and similarly treated spaces. It includes consideration of the principles of air distribution, air diffusion, and performance characteristics of all types of air terminal devices, fan-coils, active and passive beams, and high/low-pressure assemblies (air terminal units) or components, including associated or related accessories for both supply and exhaust air.

TC 5.3 has developed information on air terminal units in *ASHRAE Handbook—HVAC Systems and Equipment*, *ASHRAE Handbook—HVAC Applications*, and *ASHRAE Handbook—Fundamentals*. This guide combines the information presented in these Handbooks and goes into more detail and analysis.

Acknowledgments

The authors would like to thank Carl N. Lawson, associate at D.C. Herrmann & Associates in Tampa, Florida, for his thorough reviews and insightful comments on the drafts of this design guide, and they would like to thank Jack Stegall, general manager of Energistics Laboratory in Houston, Texas, for his help in acoustics. The authors also extend appreciation to ASHRAE staff members Cindy Michaels and Mark Owen for their help and direction in bringing this book to fruition.

The authors would also like to thank Tim Johnson, technical engineer at Holyoake Industries Ltd. in Aukland, New Zealand, and George F. Stefanovici, PE, vice president of Carastro & Associates Inc. in Tampa, Florida, for their assistance with the unit conversions throughout this book.

In addition, the authors would like to make special acknowledgment of Dr. Jerry M. Sipes, who was a colleague, a sounding board, and a great friend to many of us in this industry. When putting together a team to author this design guide, Jerry was the first pick. At the AHRI Spring Meeting in early May 2016, Jerry was presented the Richard C. Schultze award. In June 2016 at the ASHRAE Annual Conference he was awarded the Standards Achievement Award posthumously.

Gus Faris, the co-chair of the team that wrote this design guide, visited with Jerry at Jerry's home shortly before his passing. Jerry had his computer in front of him and was working on completing the acoustical chapter of this guide and his other assignments. One would have to have the greatest possible dedication to our industry considering the suffering he was going through… but that was Jerry and his pride in his work. All who knew him are better off for their time with him. We, the other authors of this design guide, wish to recognize Jerry's invaluable contribution.

Our industry lost a leader, and we all lost a friend.



Jerry M. Sipes
October 12, 1964–May 31, 2016

Acronyms

AABC	Associated Air Balance Council
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AHU	air-handling unit
AII	airborne infection isolation
ATU	air terminal unit
BAS	building automation system
BEM	building energy modeling
BMS	building management system
dB(A)	A-weighted decibel
DDC	direct digital control
DOAS	dedicated outdoor air system
EAT	entering air temperature
ECM	electronically commutated motor
EWT	entering water temperature
FGI	Facility Guidelines Institute
LAT	leaving air temperature
LCCA	life-cycle cost analysis
OR	operating room
PE	protective environment
PI	proportional plus integral
PID	proportional plus integral plus derivative
PSC	permanent split capacitor
RPM, rpm	revolutions per minute
SAT	supply air temperature
SCR	silicon-controlled rectifier
SSR	solid-state relay
UL	Underwriters Laboratories
VAV	variable air volume

Why Use This Guide?

1

GENERAL

Engineers face numerous challenges and competing constraints when designing mechanical systems for owners and operators. Owners have been challenging engineers to design systems that are more energy efficient than previous designs and have lower maintenance costs yet have low first cost. The competing constraints have stretched engineering design fees, forcing engineers and designers to use old rules of thumb and practices and foregoing today's high performance systems and practices. Most of this comes from the way engineers where mentored, seldom questioning certain design practices. A paradigm shift, a change in thought or perspective, is frequently required for engineers to be open to new ideas and solutions about common design.

This design guide introduces the history of and new concepts and applications for a common element in all air HVAC systems—the air terminal unit (ATU). For all-air systems, ATUs are ubiquitous. This guide can be used as a complete, comprehensive in-house training program for new designers. Experienced engineers and designers can navigate directly to chapters of interest. New design paradigms are introduced throughout the guide.

The following paragraphs provide a brief summary of each chapter in this design guide with key points in the design of ATUs.

The various types of ATUs are discussed and shown in Chapter 2. Also discussed in this chapter are ATU construction types, basic control options, ATU insulation options, and other accessories for the various types of ATUs.

Evolution of ATUs in all-air systems and the impact of the high-energy consumption of mid-1970s buildings with all-air systems are discussed in Chapter 3. Recent ASHRAE research projects related to the energy consumption of fan-powered ATUs are also discussed in Chapter 3. Development of new technologies, including electronically commutated motors (ECMs), is also discussed. In addition, application of ANSI/ASHRAE/IES

Standard 90.1 (ASHRAE 2016a), California Title 24 (CBSC 2016), and other industry-wide energy standards is presented in Chapter 3.

As a reference source for HVAC acoustical theory, Chapter 4 has a wealth of practical information related to ATUs. There is also a great amount of information about sound and noise in general that can serve as a reference source for acoustical theory.

Energy performance in building HVAC systems is directly related to their control systems. Controls have evolved in the HVAC industry from pneumatic, electric, and analog to direct digital controls. In Chapter 5, the design engineer can find references to the various control options for ATUs and recommended sequences of operations for the various ATUs and systems.

Chapter 6 discusses criteria the design engineer needs to know to properly specify and schedule ATUs. All too often, specifications are out of date with current practice, and schedule sheets, which use old rules of thumb, do not convey the needed information to properly select the ATUs. These out-of-date specifications and conflicting schedules result in vendor bids and submittals that vary widely. Chapter 6 addresses many of the conflicts in specifications and schedules.

By improving proper selection, the engineer can design a better system, resulting in acceptable sound levels, improved control of flow volume, proper sizing of ATUs, and optimization of energy consumption. Also, units have different performance ranges based on the manufacturer. Not all inlet sizes have the same performance. Sizing an ATU correctly can be critical to meeting HVAC system performance. The selection of the type of ATU along with motor type and heater type plays an important role in the total energy consumption of a system. Chapter 6 goes into detail on all of this with a goal of allowing designers to understand and improve ATU selection.

Chapter 6 also aids designers in identifying the types of units available and helps them evaluate the unit types to maximize system operation. Installation methods and suggestions are also discussed.

This chapter also addresses the operation parameters to be considered that can ensure that the size, type of unit, and controls are specified, which optimizes the performance of the ATUs.

Chapter 7 addresses comparison of manufacturers' ratings. Engineers should ensure that specifications require Air-Conditioning, Heating, and Refrigeration Institute (AHRI) certification on any products that are included in AHRI certification programs. AHRI certification is extremely important to establish consistency between manufacturers' catalog data that are used when evaluating performance criteria for a building.

Building energy modeling of examples is provided in Chapter 8, which addresses shortcomings of the current energy modeling paradigm about fan-powered ATUs. For this guide, an improved energy model on a annual

building energy use is evaluated using the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) large office reference building (EERE n.d.) built to ASHRAE/IES Standard 90.1-2013 (ASHRAE 2013) baseline building requirements. Simulations were performed with three different ATU selections.

Chapter 9 presents life-cycle cost analysis (LCCA) for the design engineer. Owners expect evaluation of systems to reduce owning and operating costs. The total cost of ownership between designs can only be evaluated with LCCA. Designing a project "like the last one" is no longer accepted by many building owners. The LCCA performed by the engineer adds real value to the owner.

When designing any facility to be regularly occupied, the designer must take into account occupant comfort and safety as the most important issues in the design process. Once comfort and safety are ensured, other issues such as energy should be considered. One of the more interesting aspects an HVAC designer must address is the balance between energy consumption (annual and instantaneous) and the first cost of the mechanical system (i.e., the life-cycle cost). As energy codes continue to advance toward the goal of minimal energy consumption, the mechanical system must be designed to meet that goal. This means that designers must be open to consider new technologies as well as evaluate how an existing technology such as an ATU may be best used.

ASHRAE, AHRI, and Associated Air Balance Council (AABC) standards applicable to ATUs are discussed in Chapter 10.

Testing, balancing, and commissioning for ATUs are discussed in Chapter 11.

ATU applications are provided in Chapter 12.

In addition, this design guide is accompanied by supplemental materials that can be found online at www.ashrae.org/ADGATU. These files include a collection of ASHRAE-published research on energy modeling of variable-air-volume (VAV) ATUs (ASHRAE 2016b) as well as materials that can assist in the selection, application, control, and commissioning of ATUs. This website will be updated as additional materials are available. If the files or information at the link are not accessible, please contact the publisher.

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Air Terminal Unit Types

2

Special control and acoustical equipment is frequently required in air distribution systems to properly introduce conditioned air into a space. In these systems the airflow controls primarily consist of air terminal units (ATUs), which can vary the airflow using modulating air valves, fan controls, or both. ATUs may be supplied with or without cooling, fans, heat, or reheat and with either constant or variable primary airflow rates. While maintaining a constant or variable discharge airflow rate and/or temperature, ATUs may use plenum or room air induction to affect space temperature and ventilation control. ATUs may also include sound reduction devices, heating coils, reheat coils, fans, diffusers, or cooling coils (ASHRAE 2016).

GENERAL

ATUs are factory-made assemblies for air distribution that manually or automatically do one or more of the following (ASHRAE 2016):

- Control air velocity, airflow, pressure, or temperature
- Mix primary air from the duct system with air from the treated space or from a secondary duct system
- Heat or cool the air

To perform these functions, ATU assemblies are made from an appropriate selection of the following components: casing, mixing section, manual or automatic air valve, coil, induction section (with or without fan), sound reduction devices, and local controller (ASHRAE 2016).

ATUs are typically classified as constant-volume or variable-volume devices and further categorized as either pressure dependent, where airflow through the assembly varies in response to changes in system pressure, or pressure independent (pressure-compensating), where airflow through the

assembly does not vary in response to changes in system pressure (ASHRAE 2016).

Variable-air-volume (VAV) reset controllers regulate airflow to a constant, fixed amount or to a variable, modulating amount calculated by room demand. These controllers can be electric (pressure dependent), analog or digital electronic (pressure independent), or pneumatic (pressure dependent or pressure independent). To reset the VAV airflow control device, pressure-independent controllers require an indication of actual airflow. Temperature inputs are also required for calculating room demand for comfort conditioning (ASHRAE 2016).

ATU controls are categorized as one of the following (ASHRAE 2016):

- System-powered, in which the airflow control device derives the energy necessary for operation from supply air within the distribution system
- Externally powered, in which the airflow control device derives its energy from a pneumatic or electric outside source

ATUs may be supplied by the manufacturer with all the controls necessary for their operation, including actuators, regulators, motors, and thermostats or space temperature sensors, or the controls may be furnished by someone other than the manufacturer (ASHRAE 2016).

An ATU air valve can be adjusted manually or automatically. If it is adjusted automatically, it is actuated by a control signal from a thermostat, flow regulator, or building management system (BMS), depending on the desired function of the terminal unit (ASHRAE 2016).

AIR TERMINAL UNIT TYPES

Single-Duct Air Terminal Units

Single-duct ATUs (Figure 2.1) can be cooling only, cooling/heating if the primary air unit provides both, or reheat if a heater is present. Reheat ATUs add sensible heat to the supply air. Water coils, steam coils, or electric resistance heaters are placed in or attached directly to the air discharge of the unit. This type of equipment can provide local individual reheat without a central equipment station or zone change (ASHRAE 2016).

Exhaust Valves

An exhaust valve (Figure 2.2) is a type of single-duct ATU designed for exhaust air and consists of an airflow regulator and may also include an actuator, an airflow-measuring device, and selected controls.

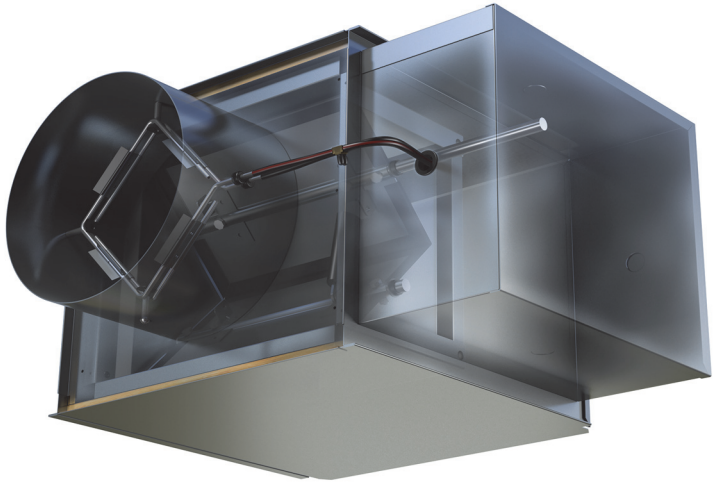


Figure 2.1 Single-Duct Air Terminal Unit
(Courtesy of Nailor Industries, Inc.)

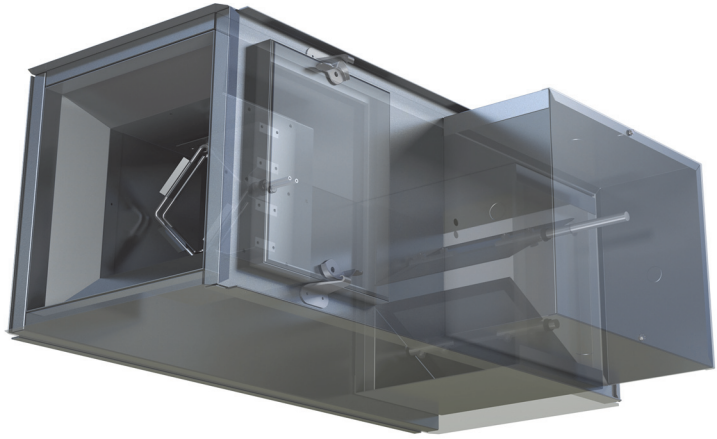


Figure 2.2 Exhaust Valves
(Courtesy of Nailor Industries, Inc.)

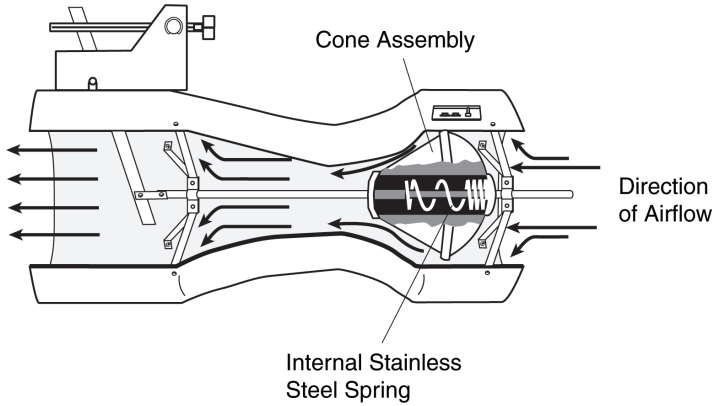


Figure 2.3 Venturi Valve
(Courtesy of Phoenix Controls)

Venturi Valves

A venturi valve is a type of single-duct ATU and can be used for either supply or exhaust. It consists of a round venturi-shaped valve body and an internal shaft that supports a cone assembly (see Figure 2.3). A VAV venturi valve also has an actuator and controller connected to the positioning arm and shaft.

The cone assembly is spring loaded on the shaft. As the pressure in the primary duct increases, the cone compresses the internal spring and moves closer to the venturi throat, increasing resistance to the airstream. As the pressure in the primary duct decreases, the spring retracts and the cone assembly moves farther from the venturi throat, decreasing resistance to the airstream. This is called *mechanical pressure independence*.

If the venturi valve is provided with an actuator to allow for variable airflow, the actuator and positioning arm reposition the shaft, which in turn moves the cone assembly relative to the throat, changing the airflow.

Dual-Duct Air Terminal Units

Dual-duct ATUs (Figure 2.4) are typically controlled by a room thermostat or sensor. They receive warm, cold, return, or ventilation air from separate air supply ducts to provide the desired room control. Volume-regulated units have individual airflow control devices to regulate the amount of warm and cool air (ASHRAE 2016).

When dual-duct ATUs provide heat and cooling air to the space simultaneously, they use reheat. When a single temperature control device regulates the amounts of warm and cold air to control temperature, a separate

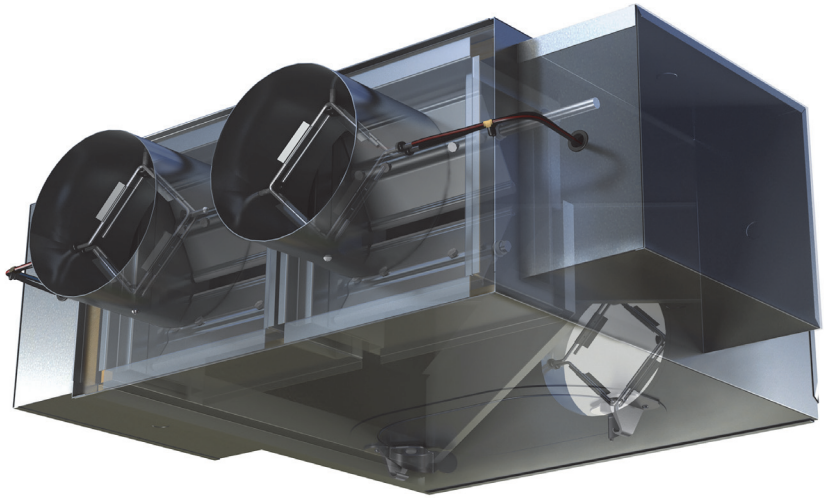


Figure 2.4 Dual-Duct Air Terminal Unit
(Courtesy of Nailor Industries, Inc.)

airflow control device may be used to control and limit airflow. To mix varying amounts of warm and cold air and/or to provide uniform temperature distribution downstream, specially designed baffles may be required inside the unit or at its discharge (ASHRAE 2016).

Dual-duct ATUs can have constant-flow or variable-flow control. These are typically pressure independent to provide precise volume and temperature control. Dual-duct ATUs may also be used with dedicated outdoor air supplied to the terminals, where the outdoor air inlet controls and maintains the required volumetric flow of ventilation air into the space. A local heating coil may be needed in dual-duct units with cooling and outdoor air (ASHRAE 2016).

Induction Air Terminal Units

Induction ATUs (Figure 2.5)supply primary air or a mixture of primary air and recirculated air to a conditioned space. They accomplish this by with a primary air jet that induces air from the ceiling plenum or individual rooms via a return duct. Cool primary air is ducted to the terminal unit and used as the inducing energy source. To modulate the mixture of cool primary air and induced air, an induction unit has devices actuated in response to a thermostat. Reheat coils may be required in the primary supply air duct to meet interior load requirements (ASHRAE 2016).

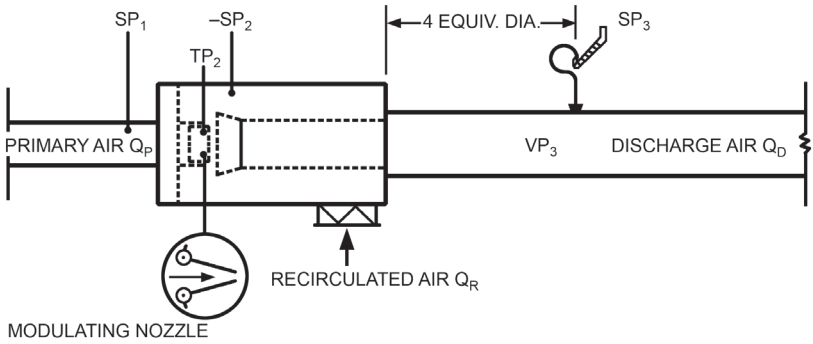


Figure 2.5 Air-to-Air Induction Air Terminal Units
(Courtesy of Titus)

Fan-Powered Air Terminal Units

Fan-powered ATUs are used in HVAC systems as secondary air handlers and typically installed in return air plenums. They are also frequently used as small, stand-alone air handlers. They differ from air-to-air induction units in that they include a blower, driven by a small motor, that draws air from the conditioned space, ceiling plenum, or floor plenum that may be mixed with the cool air from the main air handler. The characteristics of fan-powered units are as follows (ASHRAE 2016):

- In heating mode, the primary air is mixed with warmer plenum air to increase the air temperature entering the heater, thus reducing or eliminating reheat.
- Downstream air pressure can be boosted to deliver air to areas that otherwise would be short of airflow.
- Room airflow volumes can be kept high to improve occupant comfort.
- Airflow volumes may be reduced in low-load conditions to decrease noise levels.
- Perimeter zones can be heated without operating the main air handler when building cooling is not required.
- Main air handler operating pressure can be reduced with series units compared to other ATUs, reducing the air distribution system's energy consumption.
- In thermal storage and other systems with relatively low supply air temperatures, series fan-powered ATUs may be used to mix supply air with induced return or plenum air to moderate the discharge air temperature. Some units are equipped with special insulation and a

vapor barrier to prevent condensation with these low supply temperatures.

Fan-powered ATUs can be divided into two categories (ASHRAE 2016):

- Series, with all primary and induced air passing through a blower operating continuously during the occupied mode
- Parallel, in which the blower operates only on demand when induced air or heat is required

Series Fan-Powered Air Terminal Units

Series ATUs (Figure 2.6) typically have two inlets, one for cool primary air from the central fan system and one for secondary or plenum air. All air delivered to the space passes through the blower, which operates continuously when the primary air fan is on and can be cycled to deliver heat when the primary fan is off. As cooling load decreases, an airflow control device throttles the amount of primary air delivered to the mixing chamber (ASHRAE 2016).

The blower makes up for this reduced primary air amount by drawing air from the conditioned space or ceiling plenum through the return or secondary air opening. A series unit may have two ducted inlets, like a dual-duct terminal unit, in addition to the induction air inlet. The second duct is typically used for dedicated outdoor air systems (DOASs). When the units are in part-load condition, fan airflow and primary air can be varied, but fan airflow should never be less than the total amount of air supplied by the ducted inlets (ASHRAE 2016).

Parallel Fan-Powered Air Terminal Units

Parallel fan-powered ATUs (Figure 2.7) supply cool primary air directly to the mixing plenum, bypassing the fan, so that the primary air flows directly to the space. The blower section is mounted in parallel with the primary airflow control device and draws in plenum air. A backdraft damper limits the amount of primary air flowing through the blower section when the blower is not energized (ASHRAE 2016).

The blower in these ATUs is generally energized after the primary airflow has reached the minimum flow rate. Typically, the parallel unit provides constant-volume heating and variable-volume cooling (ASHRAE 2016). Although it is not recommended, these units are sometimes applied in constant-volume mode with electronically controlled motors where, to maintain constant airflow, the units gradually increase fan speed as the primary airflow is reduced. Parallel units are typically limited to one ducted supply inlet.

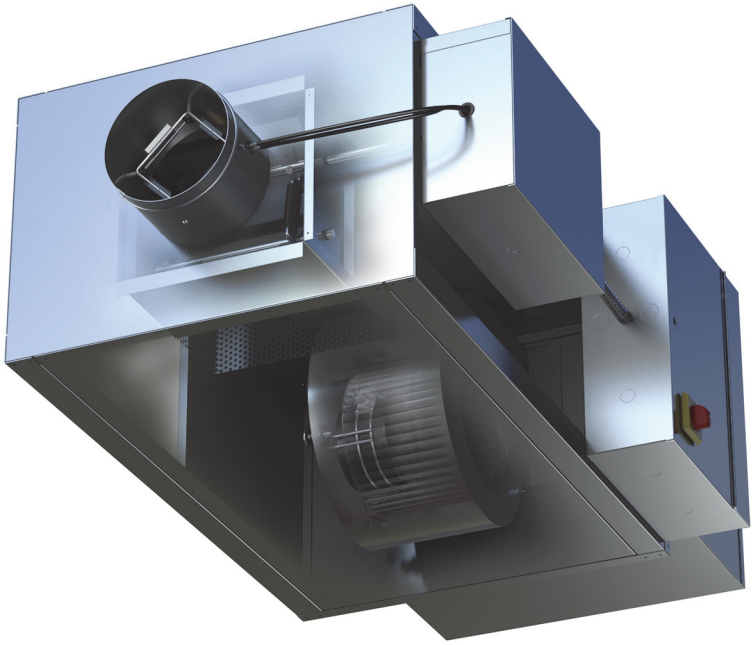


Figure 2.6 Series Fan-Powered Air Terminal Unit
(Courtesy of Nailor Industries, Inc.)

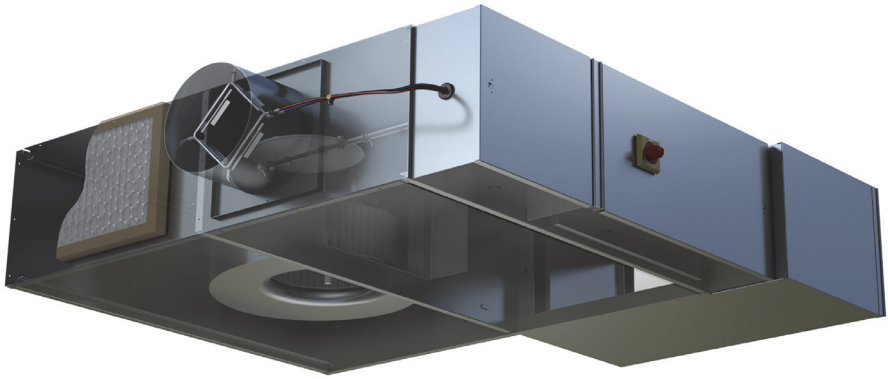


Figure 2.7 Parallel Fan-Powered Air Terminal Unit
(Courtesy of Nailor Industries, Inc.)

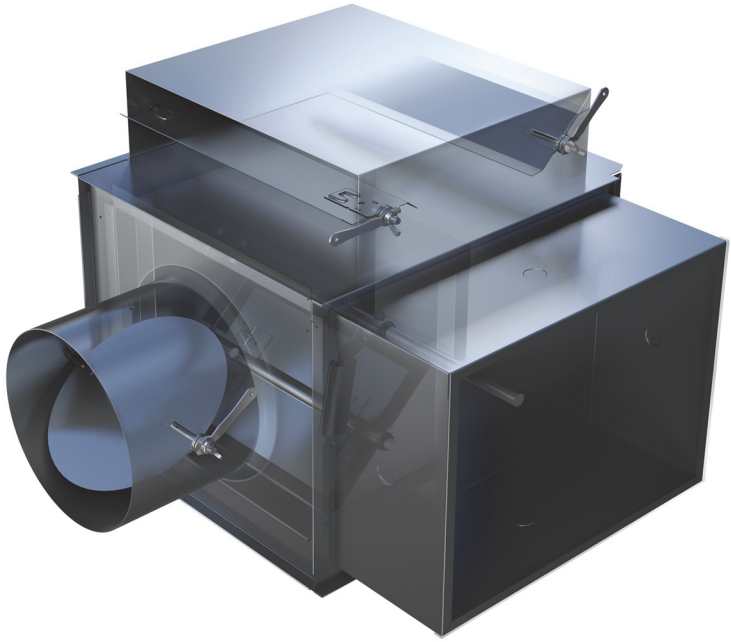


Figure 2.8 Bypass Air Terminal Unit
(Courtesy of Nailor Industries, Inc.)

Bypass Air Terminal Units

Bypass ATUs (Figure 2.8) handle a constant supply of primary air through the inlet. It reduces primary air to the zone by bypassing primary air to the ceiling plenum to meet the needs of the conditioned space. Primary air, diverted into the ceiling plenum, returns to the central air handler. This method provides a low first cost with minimum controls, but it is energy inefficient compared to other systems (ASHRAE 2016).

VARIABLE-GEOMETRY DIFFUSER

A variable-geometry diffuser (Figure 2.9) is a ceiling diffuser with an integral VAV device that can be cooling only, cooling/heating if the primary air unit provides both, or reheat if a heater is present. Electric resistance heaters are placed in the neck of the diffuser. The diffuser can only provide heat when the central air handler is energized. This type of equipment can only provide minimal local individual reheat without a central equipment station or zone change.

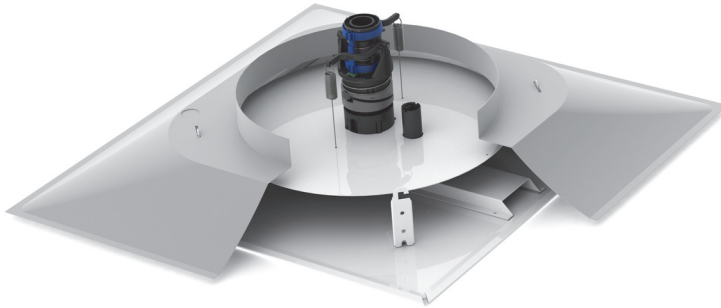


Figure 2.9 Variable-Geometry Diffuser
(Courtesy of Titus)

AIR TERMINAL UNIT BY APPLICATION

Not all ATUs are suited for all systems. Table 5 in Chapter 57 of *ASHRAE Handbook—HVAC Applications* (ASHRAE 2015) summarizes the different types of ATUs and their suitability for particular commercial building applications.

AIR TERMINAL UNIT CONSTRUCTION

ATUs are constructed of a mix of the following parts: inlets, a flow sensor, a controller, an actuator, an air valve, a casing, a liner, a mixing section, heating coils, a filter rack, fans, motors, and sound-reducing devices.

Inlets

The inlet is the round, flat oval, or rectangular duct that is connected to the primary ductwork system through a duct runout. The inlet generally houses the flow sensor and air valve. Inlet sizing is covered in Chapter 6, but as a general rule, inlets should be selected at a velocity of 2000 fpm (10.16 m/s) or less.

Flow Sensors

Flow or velocity sensors are installed upstream of the air valve in the inlet. This minimizes turbulence in the airstream that would be associated with the damper and allows for more consistent flow measurements.

Controllers

In a pressure-independent system, the controller processes inputs from the thermostat or room sensor and the velocity sensor to regulate the air valve and control airflow to satisfy set points. Controllers can be electric, pneumatic, analog electronic, or direct digital.

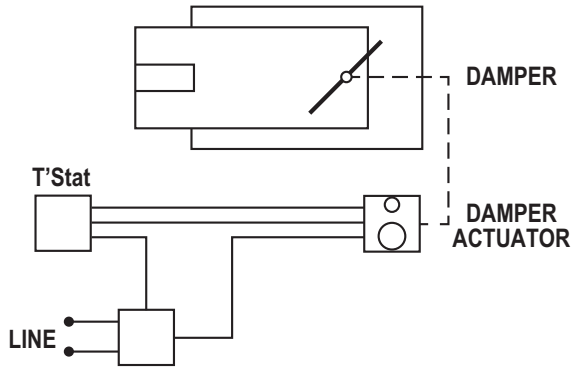


Figure 2.10 Electric Control Pressure-Dependent Diagram
(Courtesy of Nailor Industries, Inc.)

Electric Controls

Electric controls (see Figure 2.10) normally operate at low voltage, usually 24 V ac but sometimes 120 V ac. The room thermostat has single-pole, double-throw contacts so that in cooling mode a temperature rise drives the damper actuator in the opening direction and a temperature fall reverses the actuator. Because the electric system has no velocity sensor and no controller, there is no compensation for duct pressure fluctuations. Operation of the terminal is pressure dependent; the thermostat directly controls the position of the air valve with no reference to the airflow.

Pneumatic Controls

Pneumatic controls (see Figure 2.11) operate from a central system by compressed air, usually at 15–25 psi (103–172 kPa). The thermostat receives air at full pressure directly from the main air supply. In response to room temperature, the air pressure is modulated to the controller, which regulates the air valve between a preset minimum and maximum. The sensor and controller compensate for changes in duct pressure so that operation is pressure independent. Pneumatic controls are proportional only. See Chapter 5 for additional information on pneumatic controls.

Analog Electronic Controls

Analog electronic controls (see Figure 2.12) operate at low voltage, usually 24 V ac, that can be supplied by a transformer, which is installed in the control box of the ATU. These controls include either a pneumatic velocity sensor with an electronic transducer or a thermistor type velocity sensor as well as an electronic velocity controller that is pressure independent. In response to room demand, the analog signal is modulated to the

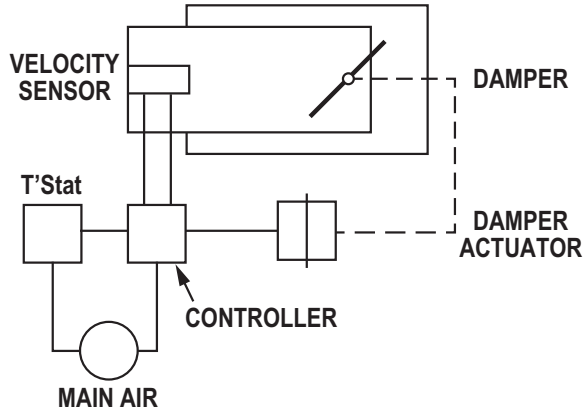


Figure 2.11 Pneumatic Pressure-Independent Control Diagram
(Courtesy of Nailor Industries, Inc.)

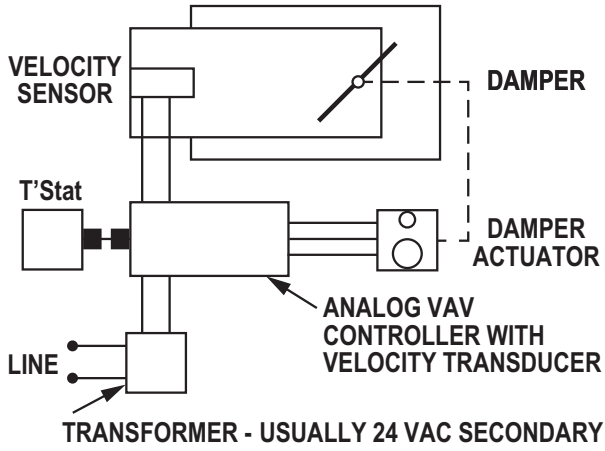


Figure 2.12 Analog Electronic Pressure-Independent Control Diagram
(Courtesy of Nailor Industries, Inc.)

controller, which regulates the air valve between a preset minimum and maximum. The sensor and controller compensate for changes in duct pressure so that operation is pressure independent. Analog electronic controls are proportional and may have an integral function as well.

Direct Digital Controls

Direct digital controls (DDCs) (see Figure 2.13) operate at low voltage (24 V ac) that can be supplied by a transformer, which is installed in the

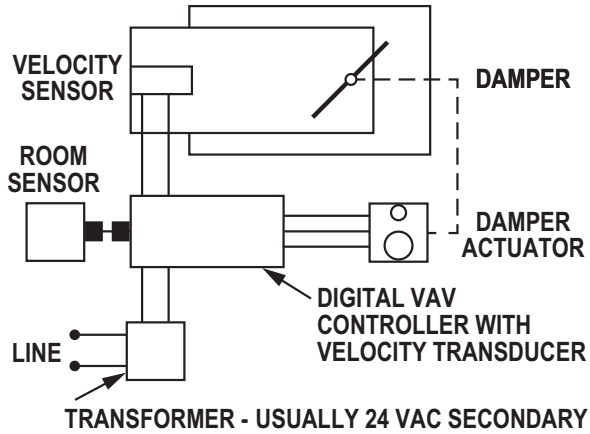


Figure 2.13 Direct Digital Control Pressure-Independent Control Diagram
(Courtesy of Nailor Industries, Inc.)

control box of the ATU. These controls include either a pneumatic velocity sensor with an electronic transducer or a thermistor type velocity sensor as well as an electronic velocity controller that is pressure independent. In response to room demand, the analog signal is modulated to the controller, which regulates the air valve between a preset minimum and maximum. The sensor and controller compensate for changes in duct pressure so that operation is pressure independent. DDCs are proportional plus integral and may be plus derivative.

Unlike pneumatic and analog controls, DDCs can be networked with all the other building equipment, developing a single system for the building. As part of the BMS, this allows remote set point adjustment and control.

In pressure-independent ATUs, the minimum and maximum capacities for airflow are set by the operating range of the transducer in the controller and the amplification of the terminal unit airflow sensor.

Actuators

Actuators stroke air valves in response to inputs from the controller to increase or decrease airflow or to hold it constant. There are pneumatic and electric actuators.

Pneumatic actuators have an internal spring that is overcome by control air pressure. When air pressure is less than the spring tension, the actuator retracts. Depending on how it is connected to a damper, the damper may open or close with a control signal increase. Normal conditions are considered to be failure conditions to maintain building operations when control systems fail. *Normally open* describes an actuator that fails open on loss of

signal or power. *Normally closed* describes an actuator that fails closed on loss of signal or power.

Electric actuators, however, are typically fail in place unless they have a return spring. Spring return actuators are not recommend and are several times the cost of fail-in-place actuators.

Air Valves

Air valves open or close in response to commands from the terminal unit controller or electric thermostat to adjust airflow to maintain set points. Modern pressure-independent air valves are round or rectangular devices. Air valve composition varies among manufacturers. In general, air valves have edge seals to minimize leakage at shutoff, limit stops to prevent the damper from overstroking, and axle shafts with bearings and linkages for opposed-blade dampers.

Casings

Casings for ATUs are generally made of galvanized steel but are also available in stainless steel. With venturi valves, the valve is its own casing and is generally spun aluminum. Casings must be supplied with adequate access for servicing and replacing critical components.

Liners

Liners provide insulation value and can provide attenuation. Basic insulation types found in ATUs include the following:

- Fiberglass insulation with a matt face
- Fiberglass insulation with a foil face
- Fiberglass insulation encapsulated in foil
- Closed-cell foam insulation
- Fiberglass insulation encapsulated in a solid metal liner (double wall)
- Fiberglass insulation behind an interior perforated metal liner

Mixing Sections

Mixing sections for dual-duct ATUs are constructed of galvanized metal with internal baffling to promote mixing of cold and hot/neutral airstreams. Dual-duct units can be ordered with or without mixing sections. Mixing sections are specified to minimize temperature stratification across discharge ductwork; without a mixing section the air temperature stratification across the discharge duct can be extreme.

Mixing sections for parallel fan-powered ATUs are constructed of galvanized metal with no internal baffle. Mixing sections are under internal positive pressure and may allow significant primary air leakage into the ceiling plenum. In the cooling mode with the fan off, the backdraft damper

at the fan inlet is under the same positive pressure as the mixing section and may allow significant primary air leakage into the ceiling plenum.

Mixing sections for series fan-powered ATUs and induction units are construction of galvanized metal. The mixing champers are negatively pressurized compared to the ceiling plenum supplying the induced air; consequently, there is no exfiltration of primary air from the ATU.

Heating Coils

Standard heating coils are hot water or electric resistance heat and are typically installed on the discharge of the terminal unit. Sometimes parallel fan-powered ATUs have heating coils installed in the inlet of the induction point, but this is not recommended because the generated heat shortens the motor life and may be a safety hazard.

Standard hot-water coils are copper tube aluminum fins available in one to four rows. One- and Two-row hot-water coils have been standard for the industry. Recently, many designs have required heating with lower water temperatures. Three- and four-row coils can achieve the required capacity but require higher system pressure. Oversizing the coils is usually a better option. Steam coils can be substituted for hot-water coils but are not common.

Electric resistance heaters are generally open-coil heating elements. The heaters can be provided with stages of heat or silicon-controlled rectifier/solid-state relay (SCR/SSR) control for capacity modulation. They offer minimum pressure drop and no water piping.

Electric heaters require internal safety devices per ANSI/UL 1995 (UL 2015). An airflow proving switch verifies presences of airflow over the heater. It will sense airflow but does not guarantee that there will be adequate airflow for heater operation. These can be electronic or pneumatic. Thermal cutouts will de-energize the heaters if they sense temperatures approaching safety limits.

Under normal operating conditions with adequate airflow, the electric heating element will operate at temperatures around 600°F (316°C). Because of the heater element's low mass, the heat is rapidly dissipated into the surrounding airflow. With low or restricted airflow, element temperature can approach 1100°F (593°C). The conductors and connectors (wires, terminal studs, wire connectors, contractor contacts, etc.) conduct heat as well as electricity. Rapid and frequent resets of the safety cutouts causes damage inside the control box due to the excessive heating of the conductors. Refer to the manufacturer installation and operation manual (IOM) for minimum airflow rates and installation direction to avoid irregular airflow.

Electric heater assemblies should be Underwriters Laboratory (UL) or ETL listed to meet National Fire Protection Association (NFPA) safety codes.

Filter Rack

Filter racks can be provided on the induction port of fan-powered ATUs. Filters are meant to be installed during construction to protect the motors from construction debris and gypsum dust. Filters are not intended to be used in occupied buildings after construction. Filters add additional pressure drop to the system, wasting unnecessary energy and additional maintenance to change out filters.

Fans

Fan-powered ATUs use forward curved fans. They are generally dual inlet.

Motors

Fan-powered ATUs were initially introduced with AC induction motors with permanent split capacitors (PSCs). Today, almost all fan-powered ATUs are equipped with electronically commutated motors (ECMs), providing significant savings.

Sound-Reduction Devices

Sound attenuators or silencers are offered for discharge and induction ports. An attenuator is commonly a lined length of ductwork attached to the end of an ATU. Attenuators can also be attached to the induced air inlet of a fan-powered ATU. A silencer is a dissipative or reactive device that is typically used when sound reduction is critical to an application.

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History and Energy

3

HISTORY OF VARIABLE AIR VOLUME AND HOW IT RELATES TO REDUCING ENERGY CONSUMPTION

The Early Days

Single-Duct Bypass Units

Variable-air-volume (VAV) strategies came into use in the HVAC industry in the 1960s. Energy was cheap then compared to today's standards, but nevertheless the pressure was on to find better comfort and lower energy consumption. The first VAV systems used bypass single-duct air terminal units (ATUs) or single-duct ATUs matched to air handlers with bypass dampers that allowed a portion of the total airflow from the air handler to bypass the occupied zones and directly return to the air handlers through the return air plenum.

In the case of bypass barometric dampers mounted in the main supply ducts off of the air handlers, the supply air was returned to the air handler inside the mechanical room. Controls were pneumatic and pressure dependent. Airflow control was accomplished by reducing the total pressure in the duct system by opening the bypass dampers. As basic as this was, energy was saved compared to the constant-volume systems that were slowly being replaced. Comfort was improved as well. The VAV ATUs installed around the perimeter of the building were equipped with either electric heaters or hot-water coils for heating. All the heat was reheat.

Modulating Fan Volume

The success of these types of systems led to a search for ways to vary the fan volume automatically and eliminate the energy used in generating the airflow that was being bypassed. Variable inlet vanes and automatically adjustable mechanical drives were also introduced in the 1960s to allow